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Microseismicity Survey of the El Hoyo-Monte Galan Geothermal Region in Nicaragua

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MICROSEISMICITY SURVEY OF THE EL HOYO–MONTE GALAN GEOTHERMAL REGION IN NICARAGUA

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KEY WORDS

microseismicity, geothermal conduits, velocity structure, modeling, El Hoyo–Monte Galan geothermal region, Marabios Range, volcano, Nicaragua

PROJECT BACKGROUND AND STATUS

At LLNL, we are collaborating with seismologists from the Trans-Pacific Geothermal Company, the Nicaraguan geological agency INETER, and the Swiss group ETH-Z to study the geothermal potential of the Nicaragua's El Hoyo–Monte Galan geothermal region in the Marabios Range volcanoes (Figure 1). INETER and ETH-Z operate a seismic network to monitor seismicity and geologic hazards in the Marabios. A planned series of seismic experiments (recording micro-earthquakes, explosions, and airgun blasts) and possible exploratory drilling in the El Hoyo–Monte Galan region gave researchers an opportunity to test various geophysical methods for locating geothermal conduits. One of these methods, microseismicity, may help discern the locations of active faults, and the characteristics of seismic propagation may point toward regions of high crack density and fluid content. Combining these potential diagnostics with electromagnetic gravity methods, near-surface temperatures, and the locations of hot springs may reveal conduits for near-surface geothermal activity. LLNL's contribution to this effort was to deploy an array of 12 seismometers in the El Hoya–Monte Galan area, and then to record and analyze microseismic data for seismic signatures of geothermal conduits. Defining possible fracture zones requires microseismicity observations to magnitude 1.5 or less. We recorded data for 20 days in March and April 1996. Additional data were collected with a similar network for three months in 1998 (W. Honjas, personal communication). From the 1996 dataset, we detected a vertically elongated cluster of episodic microseismicity 3 to 6 km deep to the northwest of El Hoyo. This seismicity consisted of small clusters of events, the structure of which could not be resolved. Our composite focal mechanism model indicates nearly horizontal N30°W compression or nearly horizontal N60°E tension.

PROJECT OBJECTIVES

Our ultimate objective is to use conceptual and mathematical models of geothermal fields as a basis for interpreting multiple datasets of geophysical data and for improving geothermal exploration techniques. The objective of this effort is to collect and interpret microseismicity data.

Technical Objectives

- Plan and carry out a joint seismic deployment in Nicaragua, recording microseismicity activity at magnitude 1.5 or less.
- Analyze microseismicity data to define possible fracture zones/geothermal conduits.
- Determine the velocity and possibly the attenuation structure in the El Hoyo–Monte Galan area.

- Work with the staff of the Trans-Pacific Geothermal Company to evaluate existing geological and geophysical data.

Expected Outcomes

- Identify a localized swarms of microseismicity that are potential geothermal drilling targets.
- To the extent the data allow, identify zones of unusually high or low attenuation that might indicate partially saturated zones or steam zones.
- Complete initial analyses of explosions and airgun recordings, and discuss results with the Trans-Pacific Geothermal Company.

APPROACH

We installed 12 three-component REFTEK seismic-recording systems with Sprengnether S-6000 seismometers. We recorded natural and man-made seismic signals continuously from March 20 to April 9, 1996, at frequencies up to 50 Hz. On behalf of INETER, we recorded a number of oceanic airgun shots, and two moderately sized explosions that took place in Lake Managua. In addition, we recorded several thousand seismic events at distances ranging from 100 km to less than 2 km from the center of the network.

The existing INETER/ETH-Z network did not have many stations in the El Hoyo area. Thus, only events larger than a ~2.5 magnitude could be located in the area of interest. We designed the 1996 seismic experiment to accurately locate microseismicity and profile the velocity structure using explosions in the adjacent lake and airgun blasts in the Pacific Ocean. During the short 1996 deployment, difficult physical access restricted instrument locations to areas accessible by road and made deploying stations in mountainous areas, such as El Hoyo, impractical. The 1998 survey provided better coverage high on El Hoyo.

RESEARCH RESULTS

To date, we have completed the analysis of the microseismicity data collected in 1996 (Smith and Kasameyer, 1997), and we have cataloged the data collected in 1998. During the 1996 deployment, the seismicity was primarily clustered in a 4-km^3 volume just northeast of El Hoyo. Examination of longer-term seismicity data from the Nicaraguan seismic network suggests that this cluster has persisted for decades (W. Teplow, personal communication). It is tempting to conclude that this area is related to either volcanic activity (as is the large cluster under Momotombo) or to intense hydrothermal flow. The overall pattern of seismicity suggests a northwest–southeast trend extending from El Hoyo to Momotombo, with a strike that is distinctly more northerly than that of the volcanic trend. However, the limited spatial extent of our network and the fact that we only recorded data for 20 days must be considered when drawing conclusions from these data sets.

The velocity structure calculated from our data (Figure 2) is consistent with Elming and Rasmussen's (1997) descriptions of geophysical interpretations in the Nicaraguan graben. They inverted magnetotelluric and gravity data in the Nicaraguan graben about 40 km southwest of our site, and found that the conductive, low-density alluvial and volcanic rocks filling the graben are up to 2 km thick, consistent with our thick, near-surface zone. This zone is underlain by a resistive (1000 ohm-m) layer that corresponds in depth to our rapidly increasing velocities to above 6 km/s. They also see a lower crustal conductor (deeper than 13 km) that they attribute to partial melt. If this feature corresponds to the lower velocities we see at depth, it must be considerably shallower.

Approximately 100 local events were recorded during the 20-day 1996 deployment. The 1996 and 1998 station locations are shown in Figure 3(a). Seismicity rates continued to be high during the 1998 deployment, which recorded 3–5 local events per day.

Location Analysis

Earthquake location accuracy depends on the number, distribution, and quality of observations, and on the appropriateness of the seismic velocity model determined during the location process. Our initial model and hypocentral locations use the output from HYPO71, a standard location code that uses a fixed velocity model with station-specific corrections. We start with the velocity model normally used by the Nicaraguan network. To prevent the near-surface velocity structure under each station from dominating the velocity iterations during solutions using VELEST, we damped the changes to the P- and S-wave velocity models more strongly than the station corrections. This allows the "best" solution to start from an initial set of station corrections, which should accommodate the near-surface heterogeneity. Figure 3(b) plots the locations to obtain the best solution for events over the whole region. Shallow events are plotted with larger symbols. The plot suggests a northwest–southeast trend of microseismicity from the northwest side of El Hoyo to the southwest of Momotombo. Locations of the events to the southwest, near Momotombo, are outside the network. In those situations, events have a large uncertainty, especially in depth, and are probably placed too deep. Within this general trend of seismicity, there is a shallow cluster northwest of the peak of El Hoyo. Experimentation with a variety of velocity models did not significantly change the location of this cluster.

The 1998 survey had better coverage to the southwest of the cluster described above. Figure 3(c) shows the results of a preliminary joint location determination for a subset of the 1996 data, and the data from the first 5 days of the 1998 deployment. The new data show that the cluster discussed above was still active, and suggest that additional events exist to the southeast.

Focal Mechanism

The stress field associated with the shallow cluster of events located northwest of El Hoyo can be derived from a compilation of the first motions observed at the seismic stations. The solutions are influenced by the velocity model and location of the events; however, this group of events is sufficiently well controlled to yield good estimates of the stress field. Figure 3(d) plots lower-hemisphere projections of the focal mechanisms for each event within the cluster. The filled quadrants represent compressional first motion; the open quadrants denote dilational first motion. As a result, the compressional P axis of stress for the solution is centered within the open quadrant, while the tensional T axis falls within the filled quadrants. Within this group of events, the most consistent stress axis appears to be the P compressional axis along a northwest–southeast trend.

Other Structural Constraints

The 1996 seismic deployment has provided strong evidence for an earthquake cluster that is associated with localized extension within an active extensional area. Because of the limited spatial extent of seismic sources and receivers, we cannot determine whether other features in the data are caused by structural variations or by attenuation variations. Under certain assumptions that have not been fully evaluated, we see some evidence for constraints on the depth of volcanic and alluvial fill, and for very high crustal velocities at depths shallower than 5 km. Finally, this study has provided tantalizing suggestions that there is a velocity inversion in the upper crust and that zones of high attenuation are associated with some volcanoes. These observations will contribute, along with other geophysical, geological and geochemical observations, to the development of conceptual model for the El Hoyo–Monte Galan area.

FUTURE PLANS

We need to complete the analysis of the 1998 microseismic data and to evaluate it in conjunction with resistivity, self-potential, thermal, and geochemical data collected by others. During part of the 1998 deployment, INETER/ETH-Z set up an additional array on an intermediate scale between our detailed survey and the Nicaraguan National network. We intend to combine the data from these three deployments.

INDUSTRY INTEREST AND TECHNOLOGY TRANSFER

Interest in this research is potentially very high.

Organization	Type and Extent of Interest
Trans-Pacific Geothermal	Supported costs of the 1998 deployment and is providing other geophysical data.

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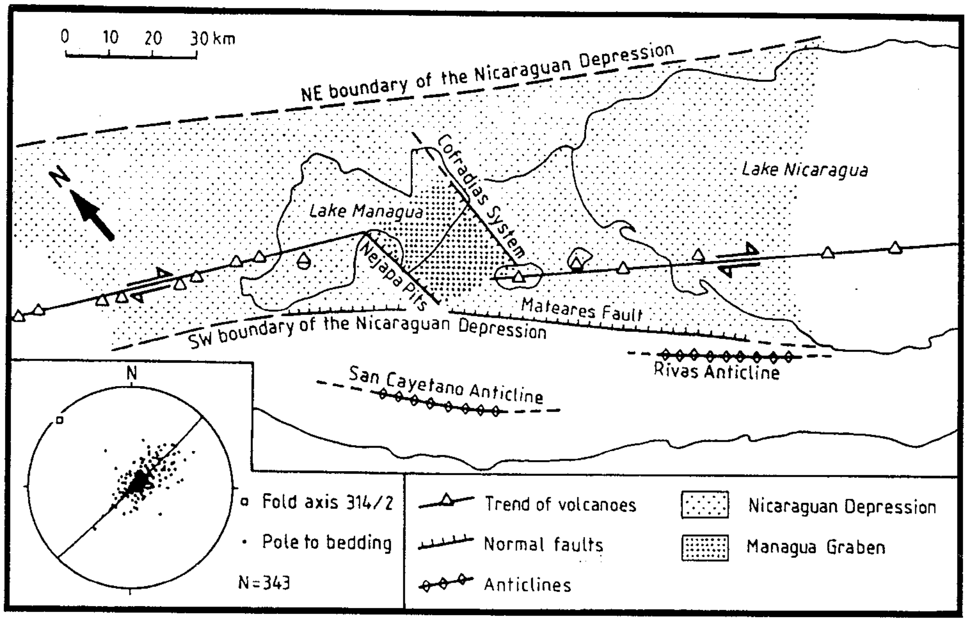


Figure 1. Map of western Nicaragua, showing major structural features (from Weinberg, 1992). The current deformation occurs as right-lateral slip along the NW–SE line of volcanoes, and in pull-apart basins caused by leftward offsets of those features. The western tip of Lake Managua is visible in subsequent figures; the first two triangles northwest of the lake are Momotombo and El Hoyo volcanoes.

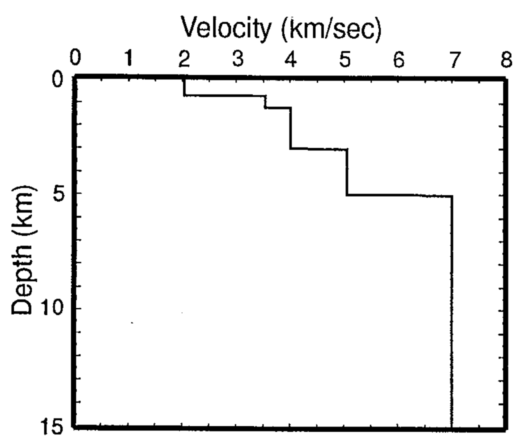
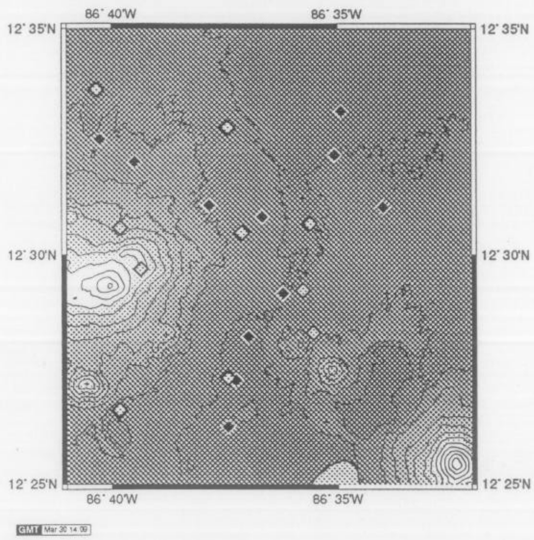
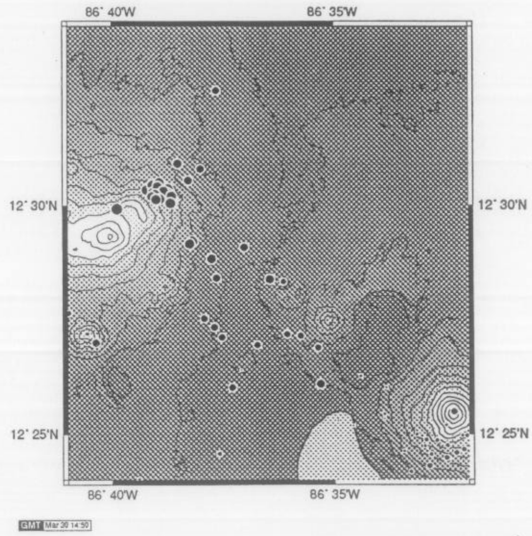


Figure 2. Candidate velocity–depth model for the El Hoyo–Monte Galan area.



(a)



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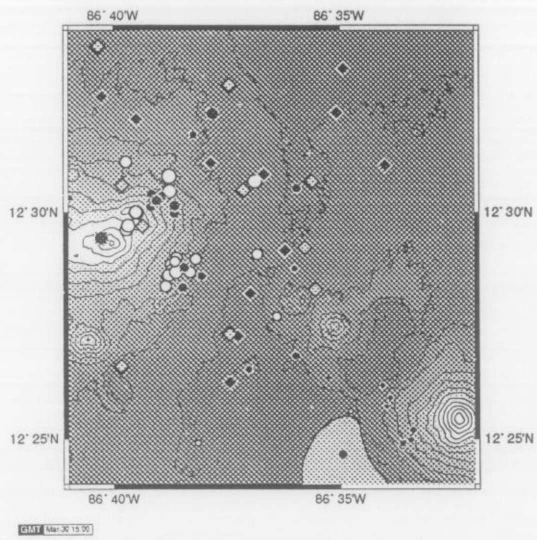
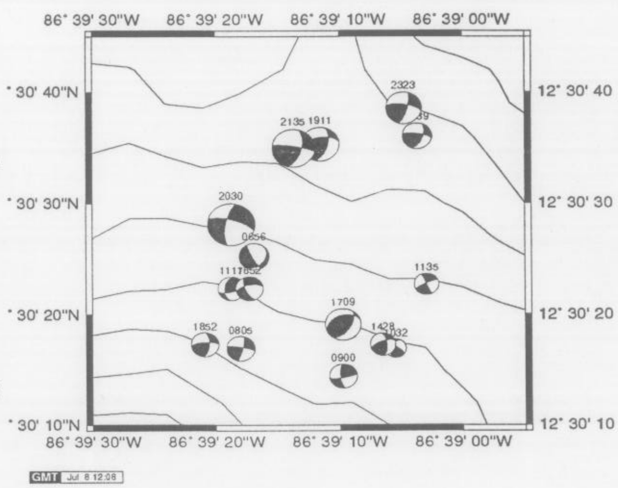


(c)



(d)

Figure 3. (a) Locations of El Hoyo–Monte Galan seismic stations from 1996 (black diamonds) and 1998 (white diamonds). Higher elevations have lighter shading. The topographic contour interval is 50. The two largest peaks are Momotombo (southeast) and El Hoyo (west). **(b)** Global location results for the 1996 seismic deployment. The black circles are locations for small M = <3.0 events, and the shallow events are indicated by larger circles. The deepening of events to the southeast near Momotombo is probably an artifact of trying to determine locations outside the seismic network. **(c)** Comparison of the location of events detected in 1996 and 1998. The black circles are 1996 events recorded with stations at the black diamonds. The white circles are locations of the first 5 days of seismicity recorded in 1998 on the stations located at the white diamonds. **(d)** Focal mechanism solutions for the cluster detected in 1996.

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